BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 03008

SUBJECT: Orbital Insertion of the Nuclear Shuttle Using a Sub-orbital Start and a Space Shuttle Booster - Case 103-8

DATE: March 5, 1970

FROM: D. J. Osias

ABSTRACT

A 300 K lb gross weight nuclear shuttle can be launched to earth orbit without a Saturn V class launch vehicle. By off loading (partially filling the propellant tanks) the nuclear shuttle and starting it before it attains orbital velocity, it can achieve orbital insertion after being launched by the first stage of a 25 K lb payload space shuttle. Once in orbit, it can be reloaded with propellants from subsequent space shuttle flights, and be ready for its intended missions. Payloads as high as 50,000 lbs could accompany the stage, except that the staging conditions (high velocity and altitude and steep flight path angle) would be such that the booster could not safely return to earth. However, by not delivering the payload on the same launch with the nuclear shuttle, booster propellant can be reserved and used for post staging maneuvering to achieve the proper reentry conditions for the booster to return to earth. Problems associated with mating the nuclear and space shuttles have not been examined.

(NASA-CR-112624) ORBITAL INSERTION OF THE NUCLEAR SHUTTLE USING A SUB-ORBITAL START AND A SPACE SHUTTLE BOOSTER (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

Introduction

The integrated manned spaceflight program for the 1970's and 1980's calls for the use of a space shuttle to reduce the cost of delivering payloads to orbit.[1] This shuttle is currently envisioned as a two stage, fully reusable transportation vehicle operating between earth and earth orbit. For transportation between earth and lunar orbit, a reusable nuclear rocket shuttle of the order of 300 K lb gross weight is planned. Because of the large weight and propellant volume of the nuclear shuttle, it cannot be delivered to earth orbit by the relatively small space shuttle, and consequently the Saturn V might be required. Two recent memoranda[2,3] discuss the use of modularized nuclear stages to eliminate the Saturn V requirement. In both these memoranda, the large nuclear vehicle is considered to be assembled in orbit from small modules which are launched by several space shuttle flights. The assembly of a large stage from small modules adds complexity to the mission and may result in increased stage inert weight and hence reduced performance. The analysis described in this memorandum shows that an off-loaded (partially filled propellant tank) large nuclear stage, started sub-orbitally, can deliver itself to earth orbit when boosted by the first stage of a fully reusable two stage shuttle. Hence a nuclear shuttle with large tanks can be used without Saturn V's, and the full nuclear stage performance potential can be realized.

Discussion

The shuttle stage used in this analysis as a booster for the nuclear shuttle is the first stage of a General Dynamics two stage, sequential burn space shuttle capable of delivering 25,000 lbs to earth orbit.[4] The characteristics of the first stage are summarized below:

Propellant Wt = 1.767 M lb

Inert Wt = 444 K lb

Thrust (vacuum)	=	4.40 M lb
I_{sp} (vacuum)	=	450 sec
I_{sp} (sea level)	=	395 sec

The nuclear shuttle for operation between earth orbit and lunar orbit uses a Nerva I rocket engine and has the following characteristics:[1]

Thrust	=	75,000 lbs
I_{sp}	=	850 secs
Inert Wt	=	75,000 lbs
Propellant Capacity	=	225,000 lbs
Diameter	=	33 feet

There is also a shroud assumed to weigh 20,000 lb which supports the nuclear propellant tank during first stage operation and is jettisoned at staging.

The shuttle booster launches the nuclear stage part way toward orbit, then separates and returns to earth for re-use. The thrust to weight ratio is limited to 4.7 or less at all times. After staging the nuclear stage begins operation and flies itself to a 55° inclination orbit. Because of the low thrust of the Nerva I engine, orbit can be achieved only if the nuclear stage is off-loaded.

Although the space shuttle/Nerva I shuttle combination is capable of delivering itself and over 50,000 lb to a 200 nm orbit, the staging conditions which would be required would prohibit the space shuttle booster from returning to earth. Table I presents the maximum discretionary payloads which could be delivered to orbit if reentry of the space shuttle booster were not necessary. Results are given for three different nuclear propellant loadings and two different orbital altitudes. The unacceptable staging conditions are also listed. The most damaging characteristic is the steep flight path angle, γ, of 18° to 40° measured relative to the horizontal. These staging conditions would result in prohibitive deceleration loads and heating on the booster during reentry. The nominal staging point for the General Dynamics shuttle is 10,370 fps velocity at 185,000 ft altitude and 2.733° flight path angle.

are negligible, whereas they are significant at larger negative kick angles.

The case of $\alpha_k = -8.0°$ will be considered in detail. If the propellant remaining in the booster is used primarily to change the flight path angle with the thrust to weight ratio limited to 4.0, reentry of the booster can start from the condition of 248,500 ft altitude at a velocity of 10,300 fps and a flight path angle of 0°. These conditions result in a maximum deceleration of 4 g and a maximum heating rate slightly higher than for the nominal 25 K lb payload General Dynamics shuttle. However, the larger 50 K lb payload General Dynamics shuttle nominally sustains a heating rate as great as that calculated here for the launch of the nuclear stage, and hence the booster reentry proposed here is considered feasible. The impact of the extra downrange distance (about 575 nm) is not considered.

In this example the dynamic pressure on the booster during its second burn is no greater than 4.0 psf at a 60° angle of attack and 1.3 psf at 90° angle of attack. A pitch modulation maneuver is used during the burn in which the tangent of the sum of the flight path angle and the angle of attack is varied linearly with time. The sum of these angles starts at about 85° and decreases to 60° at the end of the burn. If the dynamic pressure during the second burn is allowed to reach 17.5 and 8 psf at 60° and 90° angles of attack, respectively, the reentry of the booster can start from 215,000 ft at 10,700 fps and 0° flight path angle. These conditions result from an ascent trajectory with $\alpha_k = -8.5°$ and give rise to a reentry similar to that for the nominal shuttle.

A possible problem area is that of the safety of a nuclear stage sub-orbital start. Some of the considerations are discussed in an earlier memorandum.[5] It suffices to mention here that safety criteria have not yet been established, and that it appears likely that the nuclear stage can be made reliable enough to permit sub-orbit operation. Also, a 200 nm orbit would have safety advantages over a 100 nm orbit.

In summary, it appears feasible that the nuclear shuttle can deliver itself to orbit using a reusable shuttle booster, although a complex flight profile is required. Also, there are problems, such as mating of the nuclear and space shuttles, which need further consideration.

1013-DJO-baw

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Table 1. Maximum Payloads to 55° Inclination Orbits (Booster re-entry not considered)

Orbit Altitude	Nuclear Propellant	Payload	Staging Conditions* Velocity	Altitude	Flight Path Angle, γ
100 nm	75 K lb	48,260 lb	14,000 fps	391,000 ft	18.5°
100	100	53,370	13,160	458,200	26.6
100	125	47,930	12,475	525,000	36.5
200	75	45,620	13,861	434,300	22.2
200	100	50,880	13,053	489,000	30.0
200	125	45,360	12,400	550,000	40.0

*Velocity and flight path angle are relative to earth-fixed co-ordinates.

Table 2. Staging Conditions for No Payload to Orbit, Minimum First Stage Burn Time, 55° Inclination

Orbit Altitude	Nuclear Propellant	Staging Conditions* Velocity	Altitude	Flight Path Angle γ	Remaining First Stage ΔV (ideal)	Available Change in γ (ideal)
100 nm	75 K lb	9707 fps	319,600 ft	30.6°	6720 fps	35°
100	100	9026	366,850	43.9	6570	36
100	125	9387	433,140	52.8	5152	29
200	75	9808	361,735	36.3	6309	33
200	100	9169	392,500	47.6	6433	35
200	125	9480	458,800	57.5	4866	27

*Velocity and flight path angle are relative to earth fixed co-ordinates

Table 3. Dependence of Staging Conditions on Trajectory

Nuclear Stage Propellant	=	75,000 lb
Circular Orbit Altitude	=	200 nm
Discretionary Payload	=	0 lb
Orbit Inclination	=	55°

Kick* Angle	Staging Conditions** Velocity	Altitude	Flight Path Angle, γ	Remaining 1st Stage ΔV(ideal)	Available Change in γ(ideal)	Aero*** Drag at Staging
-5.5°	9835 fps	402,300 ft	43°	5996 fps	31.3°	1 lb
-6.0	9776	379,800	40	6221	32.5	2
-6.5	9808	361,735	36	6308	32.8	4
-7.0	9914	346,630	33	6300	32.5	9
-7.5	10,089	333,600	30	6200	31.6	18
-8.0	10,328	322,000	27	5992	30.0	35
-8.5	10,634	311,500	24	5708	28.2	67
-9.0	11,009	301,550	21.2	5329	26.0	128
-9.5	11,460	291,800	18.3	4847	23.0	250
-10.0	11,990	282,000	15.5	4254	19.5	470
-10.5	12,619	271,000	13.0	3533	15.6	950
-11.0	13,346	258,000	10.0	2666	11.3	2100

*Kick angle is a measure of the pitching of the vehicle almost immediately after lift-off. After this short maneuver the vehicle's angle of attack is zero until staging.

**Velocity and flight path angle are relative to earth fixed co-ordinates.

***Because the nuclear stage flies at high angle of attack (up to 70°), the aerodynamic drag must be kept small to avoid stability problems.

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